6.12 Electrochemical Advanced Oxidation

Natalia Sergienko,[a] Wenli Jiang,[a] Yanghua Duan,[a] Andrew Haddad,[b] Ashok Gadgil,[a,b] Jeffrey Urban,[b] Baoxia Mi,[a] and David Sedlak*[a]

[a] University of California, Berkeley, CA 94720
[b] Lawrence Berkeley National Laboratory, Berkeley, CA 94720
Contact information: sedlak@berkeley.edu

Motivation

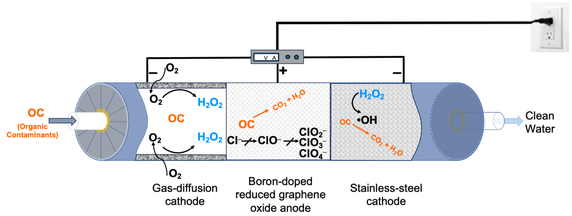
Treatment of trace organic contaminants is infeasible at small-scale due to challenges of replacing spent materials, an inability to remove certain contaminants, and economic feasibility.

Objectives

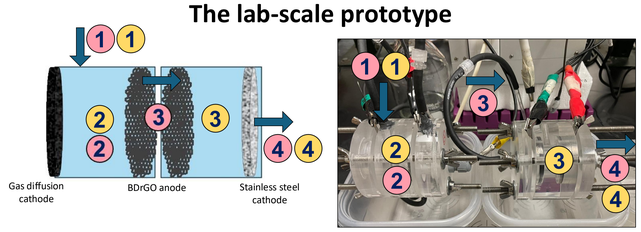
- Long-term operation of inexpensive electrodes with minimal maintenance
- Oxidation of contaminants with minimal production of toxic byproducts
- Autonomous operations that can adapt to variable influent water matrices

Approach

Electrified modular cartridge

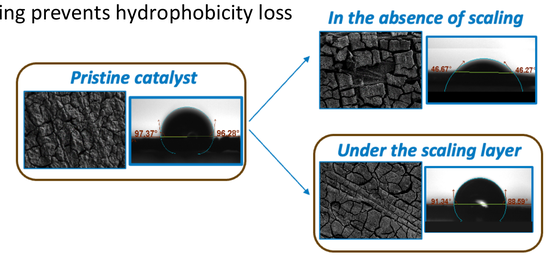


The lab-scale prototype

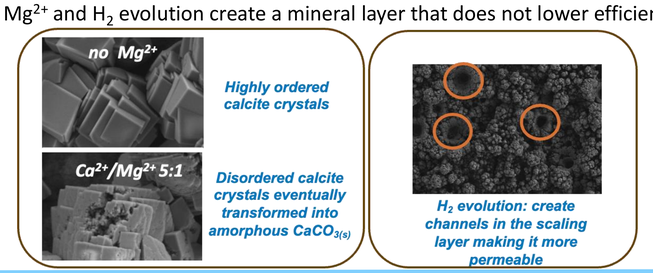


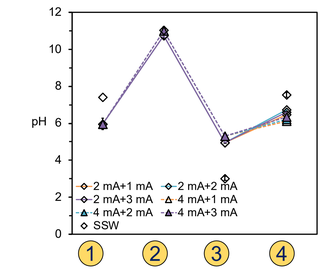
Gas-diffusion cathodes exhibit high stability

- Scaling prevents hydrophobicity loss



- Mg^{2+} and H_2 evolution create a mineral layer that does not lower efficiency



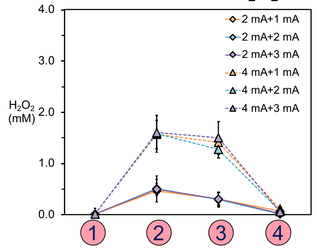


pH regulation in the electrified cartridge

- The acidic pH entering the final cathode favored hydroxyl radical generation.
- No pH adjustment is needed, as the system naturally balances pH.

Experimental conditions: 50 mM Na_2SO_4 or SSW (20 µg/L contaminants) in a single-pass system (5 cm^2 electrodes, 0.5 mL/min) with 2–4 mA on the GDC and 1–3 mA on the stainless-steel frit cathode (-0.2 to -0.7 V vs Ag/AgCl).

Concentration of H_2O_2

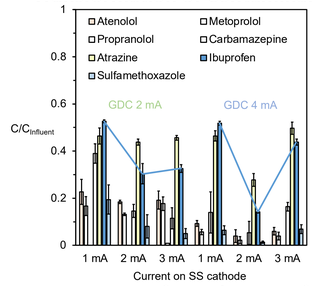


Optimization of electrochemical control

- Higher current boosts H_2O_2 production: 0.5 mM at 2 mA vs 1.6 mM at 4 mA.
- Faradaic efficiency improves: 40% at 2 mA → 64% at 4 mA.
- Complete H_2O_2 utilization: No residual H_2O_2 in effluent.

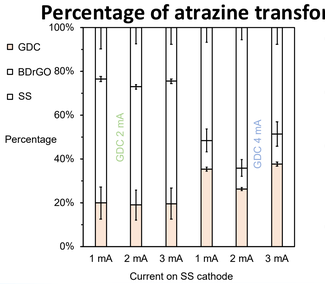
Experimental conditions: same as above

Transformation of Contaminants



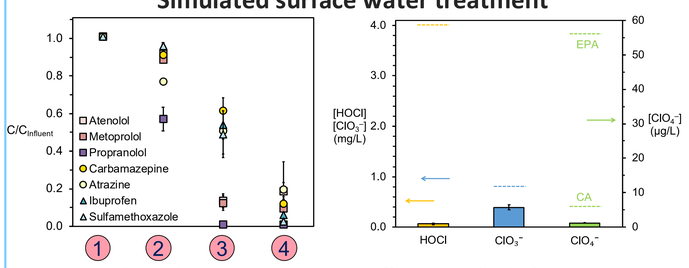
- Higher current enhances removal efficiency: 4 mA on Gas Diffusion Cathode outperforms 2 mA.
- Atrazine removal improves: ~55% at 2 mA → ~70% at 4 mA on Gas Diffusion Cathode
- Increased H_2O_2 production at 4 mA drives better contaminant removal.

Percentage of atrazine transformed



- SS cathode drives most removal (>50%) via •OH from H_2O_2 activation.
- BDrGO anode is more effective at 2 mA on Gas Diffusion Cathode
- 4 mA on Gas Diffusion Cathode improves overall removal despite lower efficiency of BDrGO anode.
- SS cathode: 1→2 mA boosts removal by increasing •OH production, but 3 mA reduces efficiency as H_2O_2 is converted to H_2O instead of •OH.

Simulated surface water treatment



- Optimized Conditions: 4 mA on Gas Diffusion Cathode for H_2O_2, 2 mA on SS cathode.
- Contaminant Removal: ~1-log in single-pass (~10s per electrode, SSW).
- Byproducts: No chlorinated byproducts above standards.

Capital and operating costs

- Capital cost: $310, comparable to under-sink RO units ($300–$500).
- Low operating cost: $0.0325/$m^3$ for energy and $67–100/year for maintenance.
- Scalable and efficient, offering a cost-effective alternative to RO systems.

NAWI CONNECTIONS

Period of Performance: December 2024

Challenge Area/Topic Area: Materials & Manufacturing
Our project aims to develop inexpensive, robust, stable electrodes to enable pipe parity for non-traditional water sources through electrified, modular treatment.

NAWI Leverage
Our project leverages NAWI resources by integrating the KrCl reactor from Project 5.21* for UV treatment, building on prior advancements in Professor Gadgil's NAWI pilot

KEY FINDINGS AND CONCLUSIONS

Key Findings:
- Successful integration of three electrodes (GDC for H_2O_2 generation, BDrGO anode, SS cathode) into an electrified modular cartridge for efficient water treatment.
- Optimized design achieved >90% contaminant removal in a single pass, with high Faradaic efficiency, complete H_2O_2 utilization, and no need for pH adjustment.
- Scalable, cost-effective system (~$309 capital cost), avoiding ion exchange membranes and minimizing byproduct formation, making it viable for distributed water treatment.

Conclusions: This project successfully developed a fully autonomous cost-competitive electrified treatment system with zero-chemical input for treatment of non-traditional water sources in small-scale applications.

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ACKNOWLEDGEMENTS

This material is based upon work supported by the National Alliance for Water Innovation (NAWI), funded by the U.S. Department of Energy, Energy Efficiency and Renewable Energy Office, Advanced Manufacturing Office under Funding Opportunity Announcement DE-FOA-0001905. Work at the Molecular Foundry was supported by the Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

This material is based upon work supported by the National Alliance for Water Innovation (NAWI), funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Industrial Efficiency and Decarbonization Office, under Funding Opportunity Announcement DE-FOA-0001905.